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Renewable Energy Powered Water Treatment Systems

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Introduction

Renewable energy is defined as energy that is generated from natural resources that are replenished both naturally and constantly – thus, from sunlight, wind, rain, tides, waves and geothermal heat. The International Energy Agency (IEA) defines renewable energy as “electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources." (IEA 2002)

In the present age, there are a wide range of motivations for powering water treatment systems from renewable energy resources, including:

- There is an increasing demand for water around the world;
- The cost of traditional fuels for power and/or thermal energy generation such gas, oil and coal are increasing;
- Security of supply – some of the traditional fuels, such as gas, are expected to be mostly used up within the next 50 years, while supplies of other fuels can depend on political stability;
- The cost of both desalination systems and RE technologies are falling;
- The need for small-systems to operate in remote areas that often don’t have an electricity grid;
- And finally, climate change is an increasing motivation – in the words of the Intergovernmental Panel on Climate Change:

> *“Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level”* (IPCC 2007)

The majority of renewable energy technologies are powered by the sun, as outlined below, except for geothermal energy and tidal energy.

Solar energy

Solar energy refers to both electricity and thermal energy that is harnessed from the sun. Solar thermal energy can be harnessed either passively – where no moving parts are required such as for passive solar building design – or actively for a wide range of applications, including domestic hot water and space heating via solar-thermal collectors. Direct-current (DC) electricity can be generated directly from sunlight using photovoltaic (PV) or solar cells that contain no moving parts. In addition, photoelectrochemical cells can also be used to generate solar hydrogen, and while this offers interesting potential for energy storage, it is neither a mature nor widespread technology and will therefore not be mentioned further in this chapter.

Wind energy

The uneven heating of the Earth by the sun results in the poles receiving less solar energy than that received on the equator. In addition, land is able to both heats up and cool down more quickly

than the oceans do. This differential heating results in the jet stream in the upper atmosphere and the characteristic winds on Earth: mid-latitude westerlies, polar easterlies, and the trade winds. Wind energy is most commonly harvested via a windmill for generating mechanical energy or a wind turbine for generating electrical energy.

Wave energy

Wave energy is in effect a stored and concentrated form of solar energy, since the waves are generated by wind passing over them, and as long as the waves propagate slower than the speed of the wind speed (just above the waves), then a transfer of energy occurs from the wind to the most energetic waves.

Tidal

Tidal energy devices exploit the natural rise and fall of coastal tidal waters resulting from the interaction of the gravitational fields of the Sun and the Moon. In some estuaries, the difference between high and low tide is accentuated and can create tidal ranges of up to 11 m. While several demonstration projects exist worldwide – notably a 240MW barrage in La Rance, France, that has been operational since 1967 – there currently no major expansions of this technology anticipated. In addition, given that this resource is more geographically restricted than those above it will not be discussed in more detail in this chapter.

Small-scale hydroelelctric energy

Hydro schemes converting the energy available in flowing water (rivers, canals or streams) into electricity. The technology is commercially and technically mature, with small-scale hydro being defined as having an installed capacity of less than 10MW. Importantly, it also has a greatly reduced environmental impact compared to the flooding of valleys required for large-scale hydro. The majority of the world’s small-scale hydro is in China.

Geothermal energy

Geothermal energy originates from heat generated deep within the earth. While naturally occurring water from aquifers with a temperature of 50 – 150°C can be used for district heating, temperatures of over 150°C are required for electricity generation. The primary disadvantage of geothermal energy is that the geological conditions that determine the quality of the resource – such as formation fluid temperature and flow rate – are difficult to predict in advance without significant capital investment in drilling and tests. Consequently, geothermal energy is regarded as a high risk investment relative to other forms of energy production.

Renewable Energy in the World Today

In 2006, about 12.3% of world total primary energy consumption (TPES, includes all forms of energy) came from renewables, with the largest large fraction (10.1%) coming from traditional biomass sources, such as wood-burning. Hydroelectricity was the next largest renewable source, providing 2.2% of TPES in 2008, as well accounting for 16% of global electricity generation (IEA 2008). Figure 1 below shows the world renewable energy supply capacity by the end of 2008 (RGSP 2009).

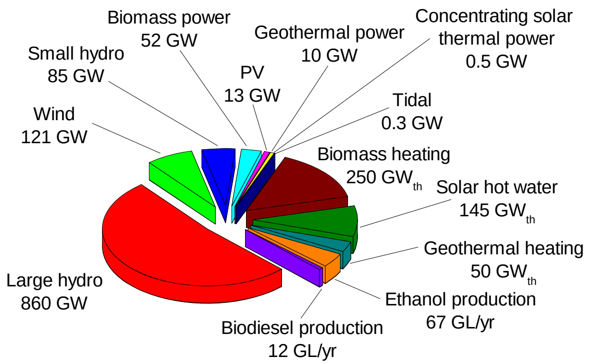

Figure 1. World renewable energy supply capacity by the end of 2008, broken down in electricity generation (units: GW), thermal generation (GW_{th}) and bio-fuel production (units: GL/yr) (RGSP 2009).

From Figure 1, it can be seen that wind power has an installed capacity of 121 MW worldwide. The wind industry this is growing at annual rate of 30%, with widespread use in Europe and the USA (RGSP 2009). The annual manufacturing output of the photovoltaics (PV) industry reached a record 6.9 GW in 2008, bringing the installed capacity to 13 MW with the largest "solar farms" operating Germany, Spain and Portugal. Several large solar thermal power operate in USA and Spain with the largest of these is the 354 MW SEGS power plant in the Mojave Desert. While being more geographically-restricted than other renewable energy sources, the world's largest geothermal power installation is located in California, with a rated capacity of 750 MW (RGSP 2009). Hydroelectricity is also, by its nature, more geographically limited and growth in this area has been less, about 8% for small-scale hydro and 3% in large-scale hydro. Brazil is leading the world in ethanol production from sugar cane, with ethanol now accounting for 18% of that country's automotive fuel consumption (RGSP 2009).

While many of the above renewable energy projects are designed for large-scale power generation for the electricity grid, several of these technologies are also very well-suited to small off-grid applications, especially in remote areas. For example, "solar homes systems" – consisting of a PV panel (20 – 100 W), battery, charge controller and DC lights – are very popular in countries such as China, Sri Lanka, India, Bangladesh and Kenya.

Therefore, in order to understand the potential for powering a water treatment system – whether water recycling or desalination – from renewable energy, it is important to have a good understanding of local resource availability. Figure 2 shows the world average availability of solar irradiance, measured as the daily number of peak sunshine hours incident on a horizontal surface at an intensity of 1 kW/m^2 (OK Solar 2009).

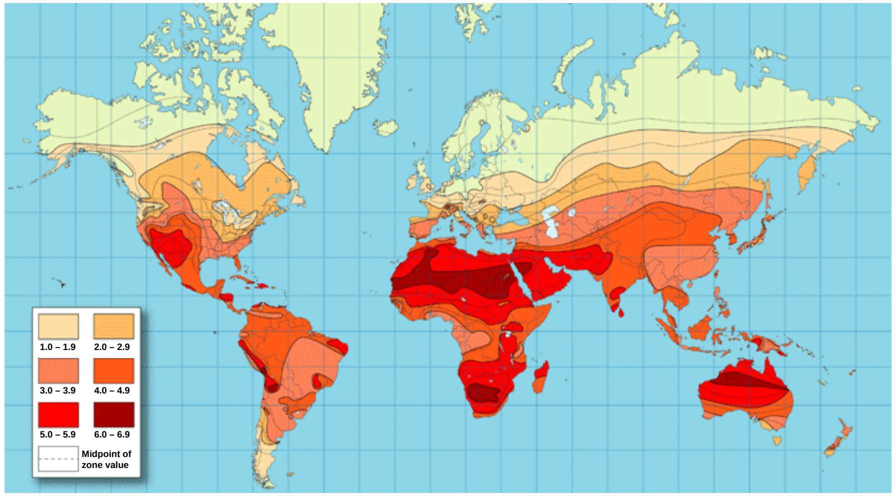

Figure 2 World solar irradiance, plotted as the number the daily number of peak sunshine hours incident on a horizontal surface at an intensity of 1 kW/m^2 (adapted from OK Solar 2009).

It can be seen that the solar radiation resource is very good throughout the North America, South America, and much of Asia, while an excellent solar resource is found in Africa, the Middle East, and Australia. While this serves as a rough guide as to where solar powered systems would be a good choice, a system designer would also need to consider seasonal variation in the solar resource and how well demand (in this case clean water) matches the supply of energy. For a critical application where, for example, the system would be the sole source of clean water for a community, solar energy systems are typically sized for the month with the least solar irradiance. This is often winter at greater latitudes, but in the tropics this usually coincides with wet seasons.

Figure 3 shows a world map of average annual wind resource, depicted as wind speed at a height of 50m based on 10 years of data (July 1983 – June 1993) (NASA 2004). As mentioned previously, wind speeds are less near the equator and reach a maximum at latitudes in the range 40 – 60° south and north, leading to the expressions the 'Roaring Forties' and the 'Furious Fifties'. It should be noted that often a synergy exists between the availability of wind and solar energy and, for this reason, hybrid systems, which rely on two sources renewable electricity to maximise water production over all four seasons.

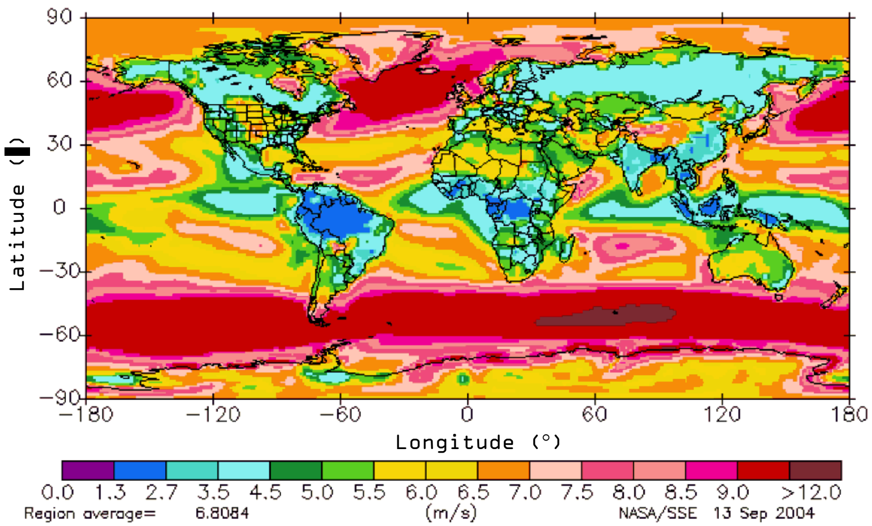

Figure 3 World map of average annual wind speed at a height of 50m based on 10 years of data (July 1983 – June 1993) (adapted from NASA (2004)).

Although marine energy is a much less mature technology than wind or PV, there are obvious synergies between marine energy availability and powering seawater desalination plants. Therefore, as an example of marine energy availability worldwide, Figure 4 shows wave energy potential worldwide, determined from 15 years of satellite data (Krogstad and Barstow, 1997). The greatest opportunity for wave energy harvesting exists along those coastlines in the world that possess a western exposure to the Southern Ocean (Chile, parts of Australia and New Zealand) as well as parts of Europe (Ireland, Scotland, Iceland) and as well as western Canada and South Africa. Additional factors when selecting a site include how steady the resource is – both in strength and direction – and therefore the most promising areas are probably the islands in the trade wind belt of the Pacific (Krogstad and Barstow, 1997). A further impetus for such development is that high cost of imported diesel that is used for power generation on these islands.

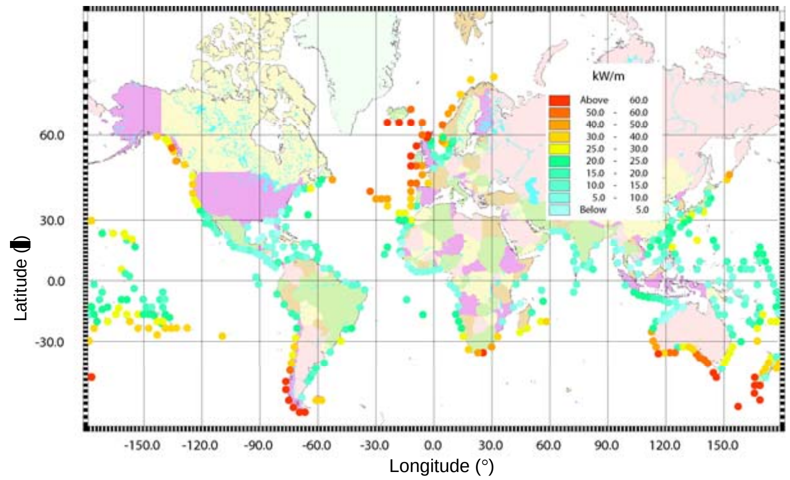

Figure 4 Wave energy estimates (in units of kW/m) along global coastlines determined via satellite data (adapted from Krogstad and Barstow (1997)).

Figure 5 compares the cost of electricity (CoE) generated from renewable energy sources (PV, wave, wind, tidal, biomass) compared to coal, gas and nuclear. For some technologies there is quite a spread in the CoE, which is influenced by the scale of the generation system and the quality of the renewable resource.

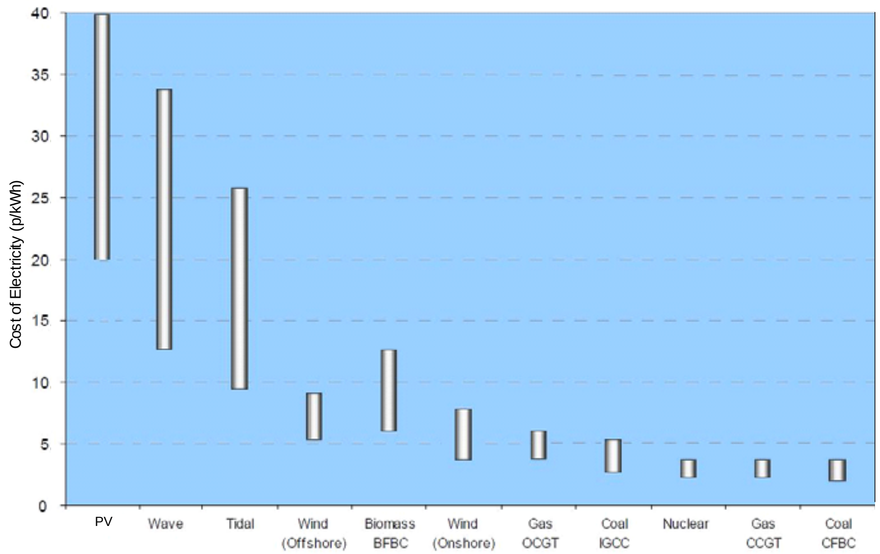

Figure 5 Cost of electricity (in British pence per kWh) generated from both renewable and traditional energy sources for the UK. BFBC = bubbling fluidised bed combustion, OCGT = open cycle gas turbine, IGCC = integrated gasification combined cycle, CFBC = circulating fluidised bed combustion (adapted from RAEng (2004)).

With the majority of renewable energy sources being variable in nature, the traditional design approach is that renewable energy powered systems will require some form of energy storage to accommodate variability in the resource availability. The only renewable energy resource that can sometimes be regarded as continuous is small-scale hydro, for streams and rivers that do not experience a dry season.

Energy storage can take many forms, including mechanical energy devices such as pressure accumulators and flywheels, and electrical energy storage devices such as batteries, supercapacitors, and fuel cells. Alternatively, if the water treatment system is connected to the electricity grid, electricity can be exported during times of excess generation and imported when the renewable resource provides insufficient power.

Renewable Energy Powered Water Treatment Technologies

The most common renewable energy technologies for powering water treatment systems in the past have been PV, solar thermal energy and wind energy. This is shown in Figure 6 for the following desalination technologies: reverse osmosis (RO) including nanofiltration, multi-effect distillation (MED), electrodialysis (ED), multi-stage flash (MSF), and mechanical vapour compression (MVC). Although, no examples of renewable energy powered water recycling schemes exist at the present time, there are plans to develop such schemes. An Australian scheme is described in a section below.

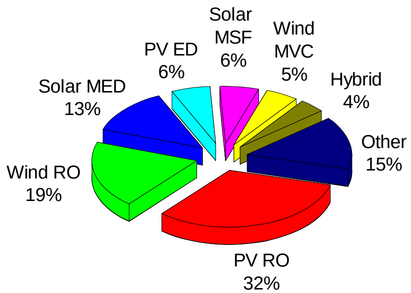

Figure 6. Breakdown of renewable energy powered desalination system technologies implemented worldwide (Tzen 2006).

Before considering the energy consumption of various technologies it is important to understand the implications of the chosen desalination technology. Desalination can be accomplished via phase change (including MED, MSF, MVC) or membrane separation (including RO, ED, NF) processes. The former all involve a phase change of the feed water (either to vapour or solid), whereas technologies like RO or ED rely on the filtration properties of polymeric membranes. The figure of merit for clean water production is the specific energy consumption (SEC), defined as how many units of clean drinking water can be produced for each unit of energy consumed (units: kWh/m^3). The SEC of a phase change process is proportional to the amount of water produced, whereas the energy requirements for a membrane separation process are proportional to the salinity of the feed water.

Table 1 below compares all existing renewable energy powered desalination technologies, highlighting the energy consumption and disadvantages of each technology. For RO and NF systems, the major energy requirement is for pressurising the feed water, with brackish water systems typically operate at pressures of about 5 – 15 bar, while seawater desalination ranges from about 40 – 60 bar. It should be noted that many technologies are still on a learning curve: overall, the SEC of Spanish seawater desalination plants has decreased from 22 kWh/m^3 in 1970, to 8 kWh/m^3 by 1990, and is presently at 4 kWh/m^3 (Sadhwani and Veza 2008).

Table 1 Comparison of all existing renewable energy powered desalination technologies.

Technology	Operating Principle	Disadvantages	Refs.
Phase change processes			
Solar still	Solar thermal energy evaporates the water, which condenses onto the sloping glass surface and it then drains into a collection trough	☒ High SEC of 639 kWh/m^3 ☒ Low daily production ☒ High maintenance costs ☒ Glass sheets vulnerable to storms and vandalism	Childs et al. (1999)
Multi-stage flash (MSF)	Saline water held under pressure at ~120°C and "flashed" into vapour in a series of ~50 chambers, which then condenses and is collected.	☒ Both thermal and electric energy required ☒ High SEC of 20 – 64 kWh/m^3 (electrical component ~4 kWh/m^3)	Block and Melody (1989) Joyce et al. (2001) Abdel-Jawad (2001)
Multiple effect distillation (MED)	Thin film evaporation process where vapour formed one chamber condenses in the next, providing a heat source for further evaporation.	☒ Both thermal and electric energy required ☒ High SEC of 15 kWh/m^3 (electrical component ~2 kWh/m^3)	Abdel-Jawad (2001)
Mechanical vapour compression (MVC)	Evaporative system where vapor boiled off in the evaporator is mechanically compressed and reused as the heating medium.	☒ Both thermal and electric energy required ☒ High SEC of 11 – 16 kWh/m^3	Abdel-Jawad (2001)
Freeze separation (FS)	Ice crystals formed in feed-water are then separated and subsequently melted to form the product water	☒ High SEC of 97 kWh/m^3 ☒ Separating ice crystals from the brine; operation in vacuum required due to lower freezing point of saline water	Block and Melody (1989), Joyce et al. (2001) Tleimat (1980),
Membrane separation processes			
Reverse osmosis (RO)	Pressure-driven separation of two solutions with differing salt concentrations across a semi-permeable membrane	☒ Low SEC of 4 kWh/m^3 for seawater ☒ Specialised chemicals not available in remote locations ☒ Chemicals required to control fouling: increases system complexity & cost, and reduces system reliability ☒ Membrane life 3 – 5 years	Block and Melody (1989) Thomson & Infield, (2005)
Nanofiltration (NF)	As above.	☒ As above, but reduced SEC for brackish water (2 kWh/m^3) ☒ Not suitable for seawater	Block and Melody (1989) Richards *et al.* (2008)
Electrodialysis (ED)	Electromigration of ions through cation and anion exchange membranes	☑ Low SEC of 2 kWh/m^3 for brackish water ☒ Chemical cleaning required ☒ No pre-treatment for removing particulates ☒ Not suitable for seawater	Block and Melody (1989) Adiga *et al.* (1987), Tablawi *et al.* (1987) Ishimaru (1994) Ortiz *et al.* (2007)
Electrodialysis reversal (EDR)	As above, however electrode polarity is periodically reversed to facilitate cleaning of ED membrane	☒ As above, however reduced chemical cleaning required.	Lundstrom (1979)

Given that the capital cost of installing a renewable energy system is high, it is naturally desirable to couple this with the desalination technology with the lowest SEC. However, this is not the only consideration. For example, if significant amounts of low-grade heat are available then perhaps one of the phase change processes could offer a lower life-cycle water cost if operation and maintenance costs are less than for RO systems.

Synergy between Renewable Energy Resource and Water Supply

It is critical to recognise that there can be synergies between the availability of a renewable energy and water resources.

One interesting example that illustrates this is the provision of clean drinking water to remote communities in outback Australia. While arid countries experience minimal rainfall and hence limited freshwater availability, there is often an abundance of solar radiation received at such locations. In addition, there are often significant groundwater reserves available, although these are often of marginal (TDS 0.5 – 1.5 g/L) or brackish (TDS 1.5 – 5 g/L) quality. This is the situation in Australia, where the majority of the rainfall occurs along the coastline, compared to 200 – 300 mm annual rainfall in central and Western Australia, as shown in Figure 7(a) (ABM 2006). The arid region in central Australia receives a daily average of at least 6.7 hours of full sunshine (kW/m^2) (ABM 2002) as shown in Figure 7(b), which is 20 – 50% more than is received along the wetter coastline. While this climate and freshwater availability reflects very strongly in the country's population distribution, as shown Figure 7(c), a large fraction of Central Australia is farmland or home to indigenous communities that often rely on poor water resources, with many communities being too small to have controlled and monitored water supplies. Drinking water for these communities is generally supplied from groundwater bores, which are of varying quality ranging from drinkable water to inconsumable brackish water. Figure 7(d) indicates that brackish groundwater can be found in significant volumes throughout the majority of Australia, mostly with good extraction rates (AWRC, 1987]. Given that the consumption of brackish water has been linked to poor health and that many of the central regions of Australia are not serviced by the national electricity grid, communities are often drinking water of substandard quality, as they do not possess the electrical power or appropriate technology to purify the water. Therefore, application and feasibility of PV-powered desalination systems, both on a small (Richards *et al.* (2008)) and large scale (De Munari *et al.* 2009) has been investigated as a sustainable technology for the provision of clean water in remote areas of outback Australia. A further advantage of solar technologies is that peak energy production in the summer months coincides with peak water demand.

A second example, in Townsville, Australia, involves the addition of a water recycling aspect to the existing Cleveland Bay Purification Plant, enabling up to 20ML of water per day to be recycled from the main treatment plant. Currently, the treatment plant discharges the treated waters into Cleveland Bay, however future limits on water and nutrient disposal necessitate the utility to develop a water recycling program in conjunction with private sector partners (Townsville Sate of the Environment 2009). A further driver is the security of clean drinking water throughout periods of drought by reducing Townsville's raw water demand. A preliminary study indicated that both the cost and energy consumption of water recycling were about 10% lower than the only other alternative of pumping in 28ML of water over a great distance and allowing 8ML losses incurred via evaporation. The potential renewable energy sources capable of powering this large-scale project include:

- wind power (in the form of two 2 MW REpower MM70 wind turbines); and
- methane, sourced from:
  - the wastewater treatment plant itself
  - a nearby landfill; and,
  - a meatworks settling pond.

This average wind speed at the site is about 6.9 m/s, which, while low for Australia, is nonetheless a valuable resource potential yielding 4.3 GWh of electricity per annum. If all proceeds to plan, this

project will demonstrate that raw water consumption of 28 ML can be reduced via the addition of a carbon neutral water recycling plant.

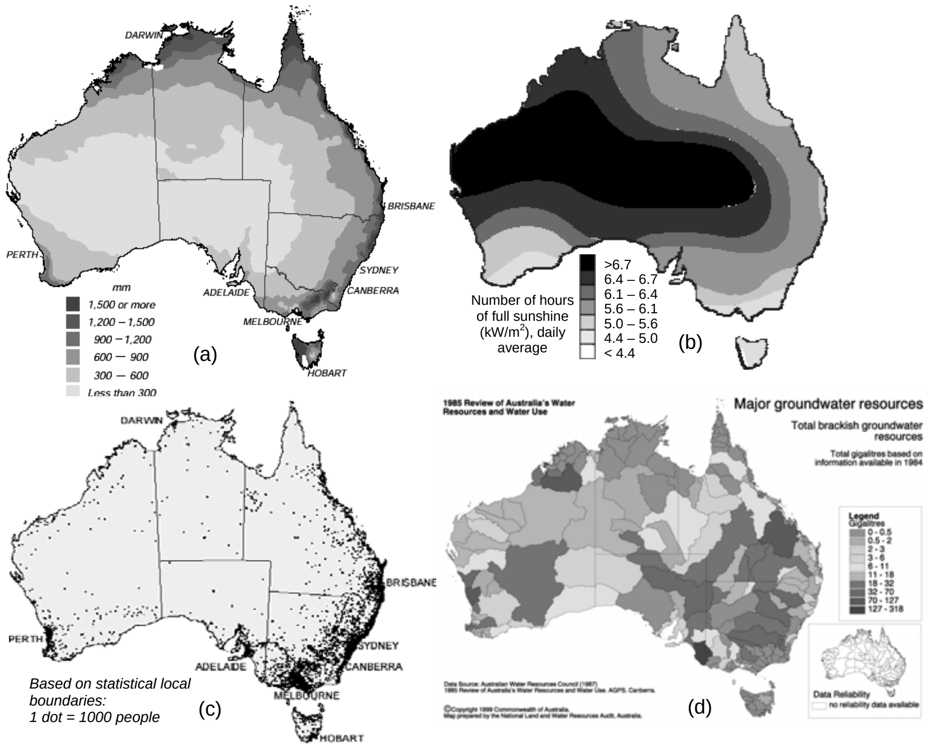

Figure 7 Australian (a) annual rainfall (BOM 2009); (b) solar radiation resource (ABM 2002); (c) population distribution [ABS 2009]; (d) major brackish groundwater resources (AWRC 1987).

Sometimes, the motivation is purely financial, demonstrating that renewable energy is no longer solely applicable for niche applications, such as remote area power supplies. This is demonstrated by a water treatment plant in California's San Fernando Valley that is powered by 1.6 MW of PV, including both crystalline silicon and thin-film technologies (Boyd 2009). The solar farm will provide almost all of the power needs for the South San Joaquin Irrigation District water treatment plant, which provides 40 million gallons/day for 155,000 residents and businesses, as well as irrigation water for 55,000 farm acres. The main goal of the project is to stabilize electrical costs, which can spike in summer months because of time-of-use metering implemented in California, which result in the cost of grid electricity reaching US$0.32/kWh, however the peak times for water demand also coincide well when solar output is at a maximum.

Small-Scale Renewable Energy Powered Membrane Filtration Plants

Membrane driven processes account for over half the existing renewable energy powered desalination in existence. Some of the reasons for this include that they are a modular technology, easy to install, compact in size, and simple to operate. Many of these advantages are also mirrored by renewable energy microgenerators, such as PV modules. These are also modular, contain no moving parts, have a long life (>20 year warranty), and involve low maintenance. The modularity of both of these technologies has also assisted in cost reduction being achieved via economies-of-scale. Wind turbines are also available in a wide variety of sizes (from 100W up to MW-scale) and multiple turbines can be included in a system design. Therefore, it is possible to scale a renewable energy powered membrane system to almost any size. These factors, combined with RO and NF exhibiting a very low SEC for seawater and brackish water, respectively, makes membranes an obvious choice when powering such systems with renewable energy.

Further advantages for small-scale systems can be realised coupling the DC output of PV modules and small wind turbines to power the necessary DC pump(s) and electronics, as well as possibly storing some energy in batteries. A DC only system increases system efficiency by 5 – 10% due to the avoidance of losses in power conversion (DC – AC) and rectification (AC – DC). In addition, the majority of renewable energy powered membrane filtration systems tend to use batteries to avoid energy fluctuations to enable continuous operation and avoid variations in pressure and flows. While energy storage enables a membrane system to produce a known amount of water at the desired quality, the use of batteries results in several problems:

i) The charge-in / charge-out efficiency of a typical deep-cycle lead acid battery is 75 – 80% (Linden and Reddy 2002) which results in a loss in system efficiency on the order of 20 – 25%. In order to overcome this loss, a 20 – 25% larger PV array is needed, substantially increasing system cost.

ii) Batteries both perform worse and degrade faster at higher temperatures, which is likely to coincide with arid regions where PV technology will be implemented. Specifically, with increasing operating temperature the battery capacity decreases, followed by the charge efficiency decreasing, and the self-discharge rate increasing (Linden and Reddy 2002). This has resulted in battery banks requiring replacement in as little as two years after installation, thus adding considerably to maintenance costs (Thomson *et al.* 2002).

iii) Even for a "long" battery-life of five years – representing over 1500 charge-discharge cycles – the battery bank will require replacement on average four times during the life of the system, since PV systems are designed to have at least a 20-year life, thus further adding to the life-cycle cost of the system.

iv) A follow-on problem is that lack adequate disposal/recycling facilities rarely exist in remote regions, and improper disposal can create further environmental hazards (Alsema 2000).

For these reasons, renewable energy powered membrane systems are being investigated where where the energy is stored in the form of the product water. This means that the system may have to be slightly oversized to account for variations in the energy resource availability, for example, to store enough water to account for a very cloudy day with minimal clean water production. However, as long as the water stored in the permeate tank remains free from biological contamination, this approach can lead to a lower life-cycle cost – and hence cost of water – as well as a much more robust system design that facilitates autonomous operation.

Therefore, it is interesting to investigate the performance of batteryless RE-membrane systems. While PV-powered water pumping systems, which are directly DC coupled between the PV panel and pump motor, operate very successfully without any form of energy storage (Thomas 1987), relatively little is known about the consequences of variable operation (flow, pressure) on NF and RO membrane systems (Schäfer *et al.* 2007; Richards *et al.* 2008). This research is being pursued for both PV- and wind-powered membrane filtration systems (Richards *et al.* 2008, Park *et al.* 2009).

Field trials performed in outback Australia have demonstrated that while relatively large variations in solar irradiance occur, due to large clouds passing overhead, the system still produces good quality water. This is demonstrated in the graphs in Figure 8, which detail the performance of a 300W PV-powered RO filtration system when treating brackish feedwater with an electrical conductivity (EC) of 8.2 mS.cm^{-1} during October 2005 (spring) (Richards *et al.* 2008). The two grey curves in Figure 8(a) show the incident solar irradiance measured on the horizontal (dashed line) as well as that falling on the PV panels attached to a single-axis (east-west) solar tracker (solid

line). This clearly indicates the advantage of having the PV modules track the path of the sun throughout the day, producing 36% more electricity throughout the day (9.5 kWh.m^{-2}.d^{-1} instead of 7.0 kWh.m^{-2}.d^{-1}). Figure 8(a) also plots the power output from the PV panels, which closely matches the solar resource availability. The maximum occurs at slightly less than the 300 W rating of the PV module due to temperature effects.

The DC power produced by the modules closely is electronically optimised to power the positive displacement pump. Feedwater is sucked through an ultrafiltration (UF) prefilter at a pressure of about -0.6 bar. The resulting feed flow reaches a maximum of about 400 L.h^{-1} between the hours of 10:00 and 16:00 (Figure 8(b)) while the transmembrane pressure (TMP) is typically around 10.5 bar during this period, as shown in Figure 8(c). Under full sunlight, the flux is around 16 L.m^{-2}.h^{-1} (Figure 8(d)), which corresponds to a daily permeate production of 1.1 m^3 with the Dow Filmtec BW30 membrane at an average permeate EC of 0.28 mS.cm^{-1}. The retention was over 96% on average, while recovery was 28%. The average SEC for this experiment over the whole solar day was 2.3 kWh.m^{-3}.

Similar experiments performed with other RO membranes including Dow Filmtec NF90, Hydranautics ESPA4 and Koch TFC-S yielded interesting results. Under similar solar conditions, the system produced 1.4 m^3 with the NF90 membrane, albeit at a slightly higher permeate EC (0.52 mS.cm^{-1}). The performance with the ESPA4 membrane looked very promising, as even on a rainy and overcast day, the system still produced 0.85 m^3 of permeate that exhibited a permeate EC of 0.81 mS.cm^{-1}, which is only fractionally over the Australian Drinking Water Guideline value of 0.78 mS.cm^{-1}, which is equivalent to 500 mg.L^{-1} TDS (ref). When using the TFC-S membrane, the system was not able to produce was of good quality (permeate EC = 2.1 mS.cm^{-1}).

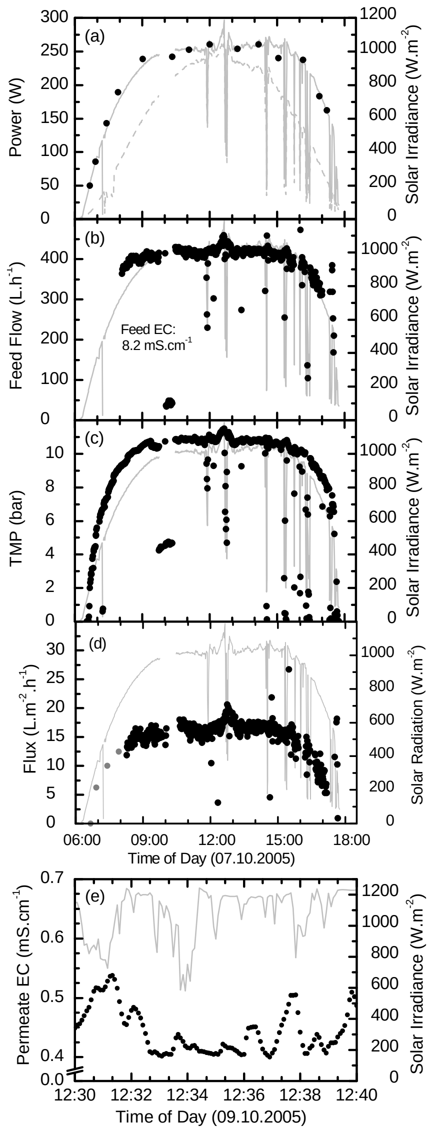

Figure 8(a) Pump power as fluctuation of solar irradiance (both tracked versus fixed) throughout the solar day on 07.10.2005. This results in (b) a varying feed flow, (c) transmembrane pressure (TMP), and (d) flux when using the BW30 membrane. Higher resolution permeate EC data (e) is plotted over short period of high solar irradiance fluctuation for NF90 membrane between 12:30 and 12:40 on 09.10.2005.

It was noted however that during periods of low power availability, the permeate EC value occasionally exceeds the guidelines. This is a result of stagnated water being flushing out of the system during periods of cloud cover. Figure 8(e) examines this effect in more detail, showing 10 min period that was recorded with higher resolution conductivity data. This shows that despite a sudden drop in solar irradiance by 50%, the fluctuation in permeate quality is minimal. These encouraging results indicate show the ability of the system to perform well under partial cloud coverage. Further research is currently underway to characterise the system further, under a wide range of fluctuating power conditions.

Conclusions

There are many motivations for choosing renewable energy technologies to provide the necessary energy to power water treatment systems for reuse and desalination. These range from the lack of an existing electricity grid, particularly in remote areas, to securing future energy and water supplies, to purely financial incentives. While many renewable energy technologies exist the two dominant ones used for powering desalination systems are PV modules and wind turbines. While wave power devices are a less mature technology, there are definitely synergies for desalination if these systems can be demonstrated to last 20 years in the harsh marine environment. Wind energy exhibits the lowest cost of electricity produced, while solar electricity is the highest. However, PV modules have a definite advantage as they contain no moving parts, thus enabling them to operate well in harsh conditions for over 20 years.

Solar technologies are particularly promising for powering water treatment schemes, given that the amount of power produced in summer will also coincide with increased water demand. The hypothesis was presented that energy storage devices may not be required, and that variations in the supply of energy could be absorbed by storing enough product water. Finally, the performance of a PV-powered membrane system filtering very brackish in outback Australia over a solar day was described. The system was able to tolerate large fluctuations in solar irradiance availability, however more extensive testing is required before a more conclusive answer can be provided as to whether the use of batteries in such systems can be truly avoided.

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